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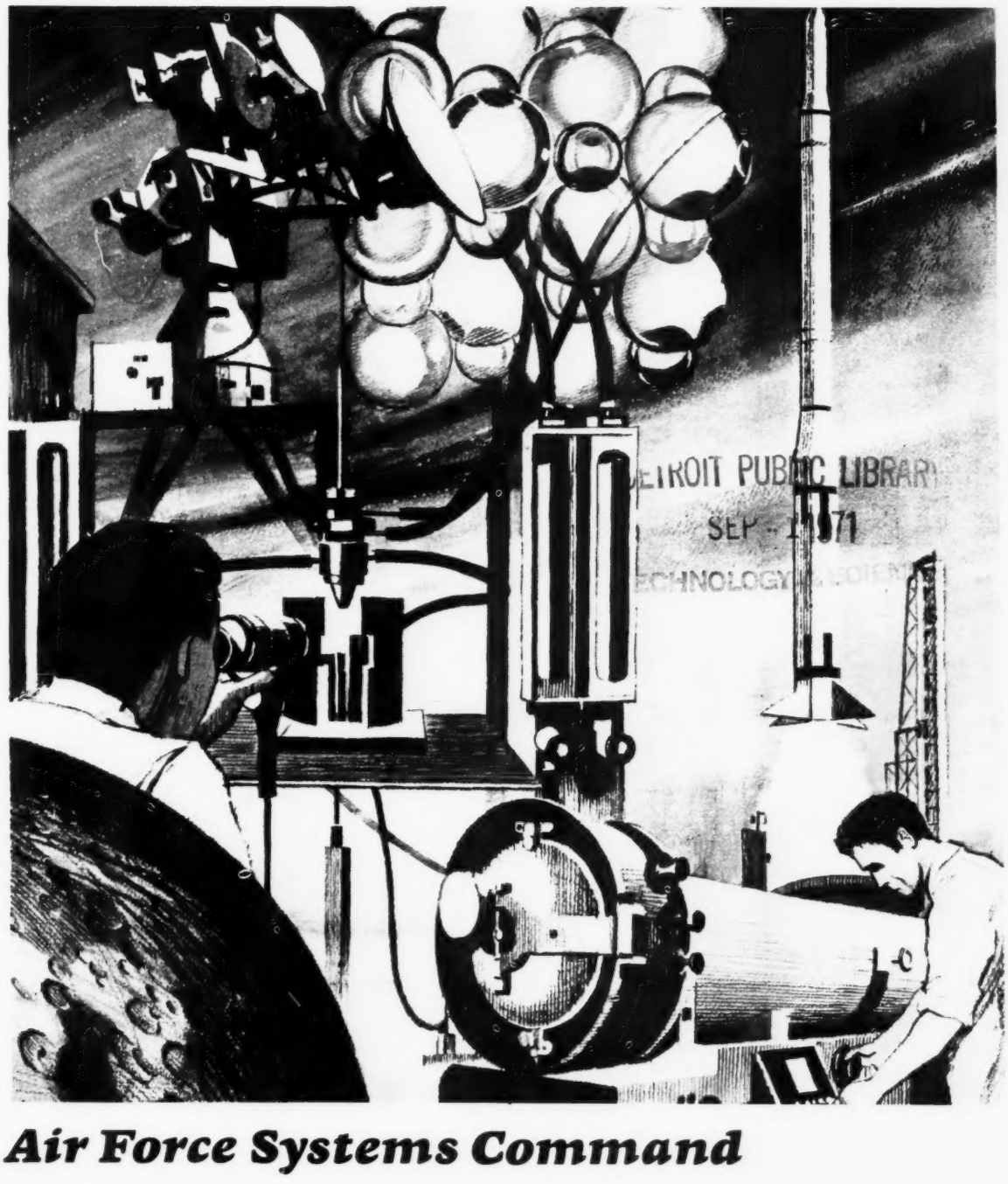
# AIR FORCE research review

Number 2

March ★ April 1971



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## Air Force Systems Command

AFSCRP 80-2

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# AIR FORCE
# *research review*

NUMBER 2

MARCH ★ APRIL 1971

The Air Force Research Review is published bimonthly. To be considered for publication in the next issue, appropriate articles related to research from AFSC laboratories should be submitted to AFSC/DLLT/PUB, Andrews AFB, Washington, D. C. 20331. It is the objective of this publication to make the scientific community aware of the progress, results, and problems of Air Force conducted or sponsored unclassified research.

ETHEL GAMER, *Editor*

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# FOREWORD

The current issue of the Air Force Research Review includes a new section called "Scientific Notes" which comprises short preliminary descriptions of the results of research. These notes should reduce the time lapse between a discovery and a final long report on the subject. Thus the result becomes more quickly available to other scientists for use in further research or technological advancement, or for their constructive comments or suggestions either sent directly to the originating scientist or published in the Review as a suggested application of the research.

To further meet the objectives of the Air Force Research Review, particularly to publicize the personal achievements of Air Force research scientists, it is now proposed, with the cooperation of the laboratory scientists and the laboratory focal information points to add the following types of information to the Review in a section called "News":

- Announcements of symposia, seminars, meetings, and speeches, each to include date (within the ensuing quarter), location, and topic.
- Announcements of brochures of AFSC research laboratories and of articles published by AFSC authors in scientific journals, and reviews of books written by AFSC scientists.
- Achievements of AFSC scientists, including appointments to key positions, awards and honors received, patents awarded, and invention disclosures.

These changes are not intended to substitute for the usual articles describing a milestone or final result of a research project, the primary purpose of the Review. Each article, which may be of any length appropriate to the importance of the result, should be accompanied by illustrations (drawings or photographs), a bibliography, and short biographies and "action" photographs of the authors. Instructions on security requirements, format, etc. may be found in Attachment 1 to AFSCR 80-37. Further questions should be referred to the Editor, Autovon 858, Extension 2287, or Area Code 301 981-2287. Suggestions will be welcomed for other additions or changes to the Review that will increase its value to you.

At the end of each article, scientific note, research advance or need, etc. the person or persons to contact for further information is usually given, together with the latest available telephone extension. The laboratory at which the scientist is located is shown either under the title of each article and scientific note or following the scientist's name. The last page of this issue contains a list of AFSC laboratories, their addresses, and various telephone numbers. The list is alphabetical, except for the initial grouping together of all laboratories located at Wright-Patterson AFB. Combining the pertinent information thus given should make it relatively simple to contact the scientist, when necessary.

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# Vortex Interactions In Modern Aerodynamics

CAPTAIN DAVID FINKLEMAN
Directorate of Aerospace-Mechanics Sciences, FJSRL

**Introduction**

Recent interest in the hazards of aircraft wake turbulence has reminded the aerospace community of the importance of vortex phenomena in aerodynamics. There can be no lift without accompanying vortex wakes. A discussion of several phenomena whose existence depend upon the generation of vorticity was recently given by Dr. Quinn in this publication (1). The vortex systems of concern therein were unhampered by the existence of boundaries; vorticity was added at a constant rate so that the circulation per unit length of vortex filaments was invariant. The problems currently being investigated at The Frank J. Seiler Research Laboratory are of a different class. We are concerned with the influence of nonuniform vortex shedding on the aerodynamics of slender aircraft. The problem of particular interest is the interaction of a canard surface with a nearby wing.

Aircraft pitch control through deflection of horizontal surfaces behind the wing aerodynamic center is detrimental to net lift. Rotation through elevator or elevon deflection decreases lift under just the circumstances that require an increase. Thus, canard surfaces are well suited to any situation in which high maneuverability at moderate speeds is necessary. The disadvantages of canard surfaces far forward of the wing aerodynamic center are well documented; hence, the investigation to be described is concerned with close-coupled wing-canard configurations. The SAAB Viggen has recently exploited the advantages of this combination of lifting surfaces.

Wing-canard interactions have been studied extensively. When the vertical separation of the surfaces is small and horizontal separation is less than or equal to the product of the chord (c) and the aspect ratio (AR) divided by the lift coefficient ($C_L$), ($c \cdot AR/C_L$), the canard wake can be assumed flat, and standard methods of lifting surface theory may be applied (2).

On the other hand, if the surfaces are slender and/or horizontal separation is large (e.g., B-70 type aircraft), the leading-surface wake may be assumed to be fully rolled-up into concentrated vortices (3).

The methods developed at FJSRL apply to the intermediate region in which the canard wake is neither flat nor fully rolled-up. Situations of interest are those in which vertical and/or horizontal separations are on the order of the length of the leading surface chord.

**Analysis And Results**

Sharp edged slender planforms exhibit separation at or near the leading edge. Vortex sheets near the edges of such planforms lead to normal forces which, in many cases, are comparable with those due to the imbedded attached flow. The methods developed in this investigation account for the effect of vortex wakes shed from leading and trailing edges of the canard surface upon the strengths of vortex sheets on wing leading edges. The situation of interests is shown in figure 1.

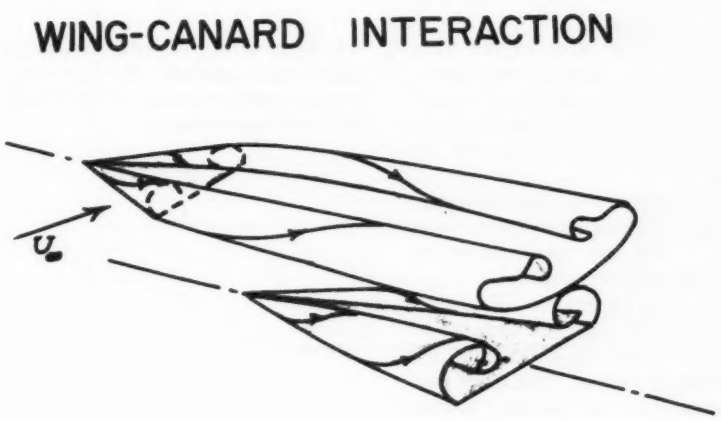


**Figure 1. Delta wing-canard interaction.**

From the several appro s to the vortex shedding problem t ere investigated, one by Sacks ( vas chosen. So far as we know, ours he first major application of this me 1; several modifications of the th were necessary. The wing is divi into a number of chordwise segmen. At each segment is shed a vortex whose strength is sufficient to suppress the infinite velocities which potential theories (i.e., inviscid) would require at the edges of the wing. The strength of these vortices is greatly influenced by the presence of vortices shed upstream. The details of the method and also several innovations in numerical analysis which resulted from this study are described in (5).

Typical results are shown in figure 2 in which the variation of normal-force coefficient with incidence is plotted. The coefficient is based upon the sum of wing and canard areas; thus, when wing and canard are not allowed to interact, the results represent the performance of the wing or canard alone. The upper curve illustrates the magnitude of separation-induced forces relative to those of the linear attached flow. When a canard and wing, each of aspect ratio 1/2 are separated both vertically and horizontally by an amount equaling 1/4 of the canard chord, the separation-induced forces on the wing are degraded. The three major reasons for lift degradation are:

(1) Near the apex of the wing, the path of the canard vortex core is nearly straight. As the wing grows and the core approaches the wing tip, the impulse of the vortex system decreases.

(2) Canard vortex rotation forces the wing's leading-edge vortex sheet nearer to the edge and leads to reduced vortex system impulse.

(3) The presence of canard vortices requires that less vorticity be created at wing edges so that net circulation is reduced. This effect may be beneficial in practice. Vortex bursting and attendant stall occur earlier when the vortex system is stronger. By reducing the strength of the wing vortex system, the canard delays stall. Generally, the first effect predominates, and wing center of pressure is moved rearward.

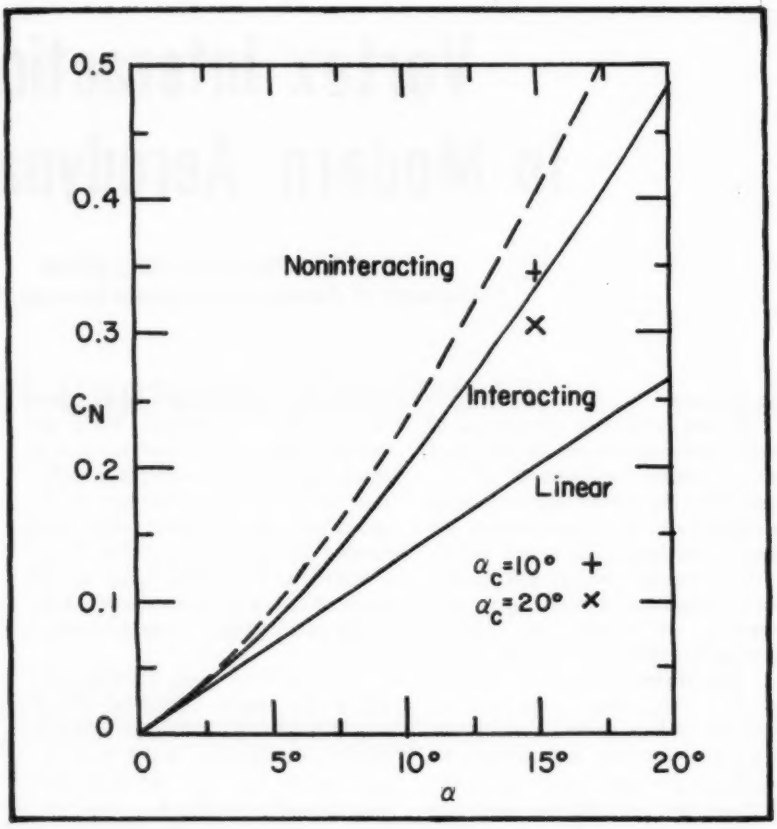


**Figure 2. Normal force on wing-canard combination.**

**$AR_c = AR_w = 0.5$; $S_v/C_c = S_h/C_c = 0.25$; $C_c/C_w = 0.5$**

An interesting result is illustrated in figure 2. For a wing incidence of 15°, the canard was misaligned by ±5°. When the canard is at a lower incidence that the wing, the canard vortex wake is farther away from the wing than when the two surfaces are parallel. Although the canard lift is decreased, the derogatory influence of the canard upon the wing is reduced, and the wing gains more lift than the canard loses. The outcome is a control reversal wherein increased canard incidence leads to decreased net lift. This is an example of direct lift control in which the leading surface directly affects trailing surface pressure distribution.

Other interesting phenomena are illustrated in figure 3 in which the wing apex and canard trailing edge are coincident. The downwash field of the canard is so strong that the wing senses an overall negative effective incidence near its apex. Separation induced normal forces near the apex are therefore negative. In general, for separations which are a small fraction of the canard chord, there is a region of negative loading near the wing apex. Since a nonlifting wing segment is of no use, it would be to remove the negatively loaded wing segment and to add the corresponding area to portions of the wing upon which vortex interaction is more favorable.

**Conclusions**

A method has been developed for predicting the aerodynamics of close-coupled wing-canard planforms. Pertinent applications exist in STOL, highly maneuverable aircraft, direct lift control, and control configured aircraft. Significant advances in computation of numerous vortex paths have been made.

Contact: Capt David Finkleman
Telephone Ext. 3122

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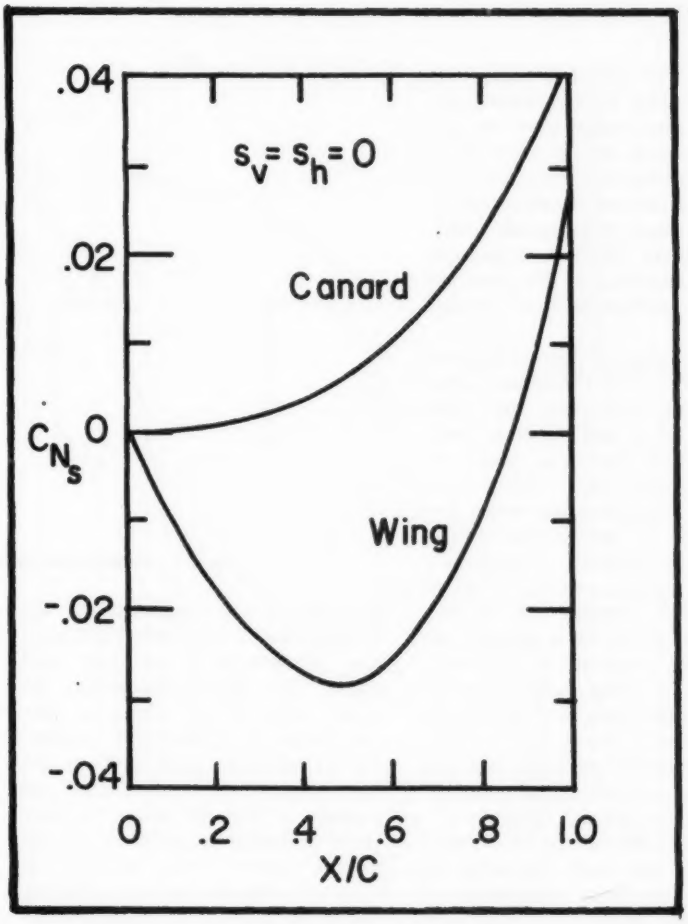


**Figure 3. Separation induced normal force.**

$\alpha_B = \alpha_W = 15^\circ$; $AR_C = AR_W = 0.5$; $C_C/C_W = 0.5$

# Methods of Eliminating Phased Array Blind Spots

DR. ROBERT J. MAILLOUX
Microwave Physics Laboratory, AFCRL

During the past few years, engineers responsible for the development of phased array radars have observed radiation pattern nulls at angles which should be within the normal scan cone of the array. Because phased arrays for military systems are extremely costly, their reliability must be unquestionable; the occurrence of this phenomenon can sometimes seriously degrade the system.

These events have stimulated researchers to study the complex electromagnetic phenomena associated with these effects and to seek methods of eliminating them. The physics of the array "blind spot" is now relatively well understood, but methods of avoiding the problem are less obvious and often inconvenient. The anomaly is due to mutual coupling of the individual array elements. At a scan angle at which a null is present, the field can be described in terms of a forced non-radiating surface wave in which the only fast wave in the spatial harmonic spectrum is one whose radiation is completely canceled. A similar leaky wave analysis can be used for angles near, but not at, a blind spot.

The AFCRL Microwave Physics Laboratory has made mathematical studies of the basic phenomena of array mutual coupling and blind spot occurrence, and is also continuing to search for array matching techniques to eliminate undesirable features in the array scan cone. Whenever an array surface is modified by the addition of some new matching element, the scanning properties are altered; however, in addition to the possibility of improving array match, new blind spots may be introduced at other scan angles. To further complicate the study, some of the associated phenomena are dominated by the interaction of waveguide higher order modes. This interaction requires that the analysis of phased array boundary value problems be performed in the most complete manner possible and that the models of compensating devices be accurate mathematical representations of the physical objects. To date, the Laboratory has studied the use of dielectric layers, stratified dielectric layers, and several types of metallic fence structures for array matching. Figure 2 shows an example of matching achieveable with the metallic fence structure of figure 1. In this case the unperturbed array (h = 0) does not have an actual blind spot, but does have a sharp dip in the pattern at the onset of the grating lobe ($\sin\theta = 0.75$). As the height is increased, that dip becomes a full null, broadens, and moves inward to appear at smaller scan angles. This feature is most exaggerated by the data with $h = 0.5\lambda$. Beyond this height, the blind spot disappears and the array element pattern assumes a shape that allows scan slightly beyond the grating lobe angle. At a scan angle of 53°, the grating lobe is at -72° and is suppressed 4 dB with respect to the main beam, and the main beam power is increased 1.76 dB as compared with the h = 0 case. This result indicates that if addi-

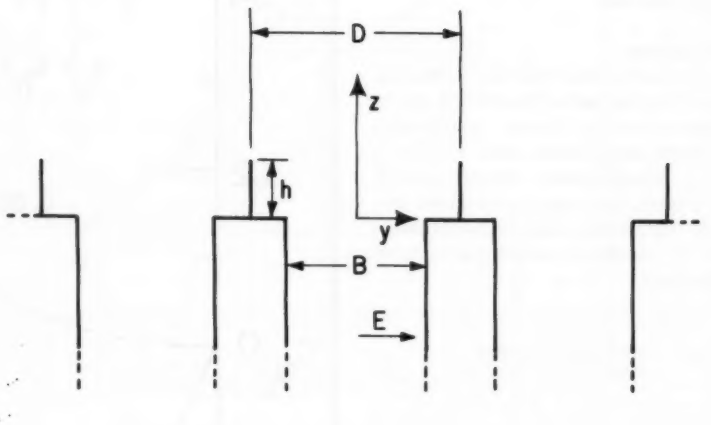


**Figure 1. Metallic fence structure for phase array matching.**

tional array shielding methods can be used, it would be possible to increase the maximum scan angle by as much as 5° without sacrificing performance—a considerable improvement in capability.

Other uses of array matching techniques, in addition to this capability of scanning beyond the grating lobe angle, include shaping the array element pattern to accent or suppress certain spatial regions or to provide near optimum impedance match over limited scan angles.

*Dr. Robert J. Mailloux has been a research physicist at AFCRL's Microwave Physics Laboratory since April 1970. He conducts research in the areas of antennas, periodic structures, and phased array phenomena.*

*He received the B.S. degree in Electrical Engineering from Northeastern University, Boston, Mass., in 1961 and the S.M. and PhD degrees from Harvard University, Cambridge, Mass., in 1962 and 1965, respectively. He was with the NASA Electronics Research Center, Cambridge, from 1965 to 1970, and was also a research fellow at Harvard University during 1966 and 1967.*

*Dr. Mailloux received a Special Achievement Award from the IEEE in 1970 for a paper describing his work on the interaction of antenna elements. He is a member of the IEEE, Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.*

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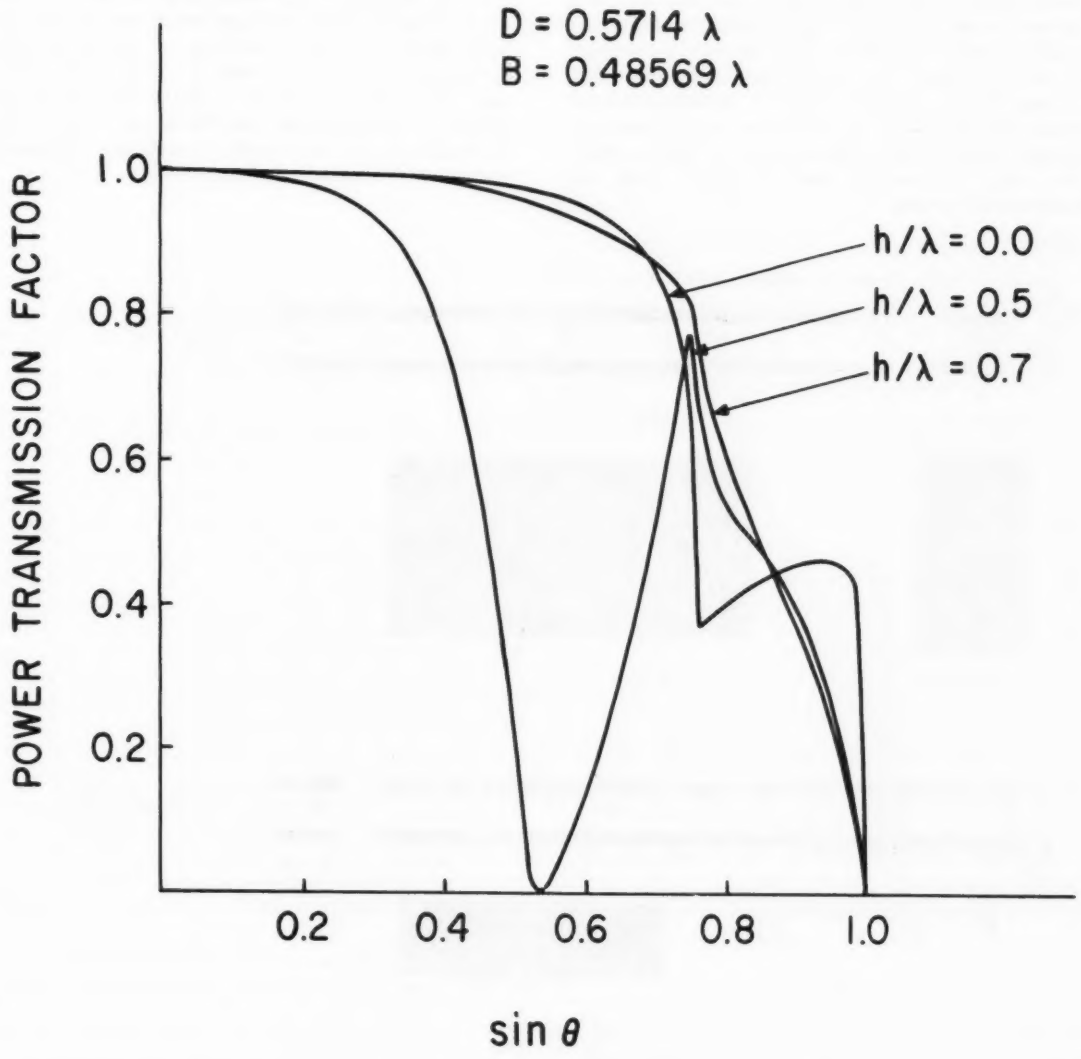


**Figure 2. Power transmission factor for various fence heights.**

# Signal Processing With Elastic Surfaces

PETER A. DEVITO, PAUL H. CARR,
WILLIAM J. KEARNS, AND JOSE H. SILVA, JR.
Microwave Physics Laboratory, AFCRL

**ABSTRACT**

Advances in elastic surface wave technology are giving rise to new classes of compact, lightweight signal processing components. Although still a relatively new technology, surface acoustic waves have rapidly progressed from their use as delay lines to the performance of sophisticated signal processing functions such as correlation. In addition, multiple tapped surface wave delay lines can be used to generate the complex waveforms used in modern radar and communications systems.

The Microwave Acoustics Branch (AFCRL) has recently designed, fabricated, and tested new acoustic surface wave devices for use in encoding and decoding binary information. These devices were first requested by and subsequently delivered to the Communications Technique Branch, Communications and Navigation Division, RADC, for studying their applicability to wideband, multifunction communication and navigation systems.

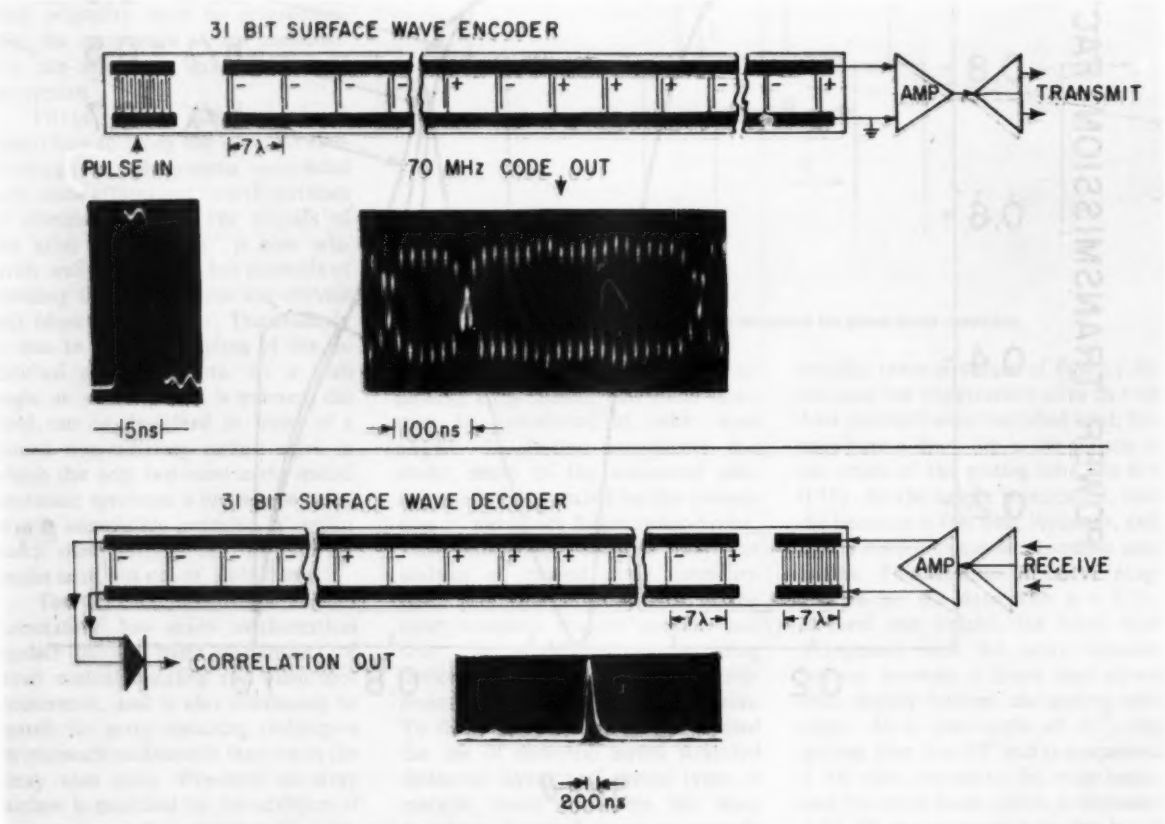


**Figure 1. Pictorial representation of the encoding and decoding of a single information bit in a communications application.**

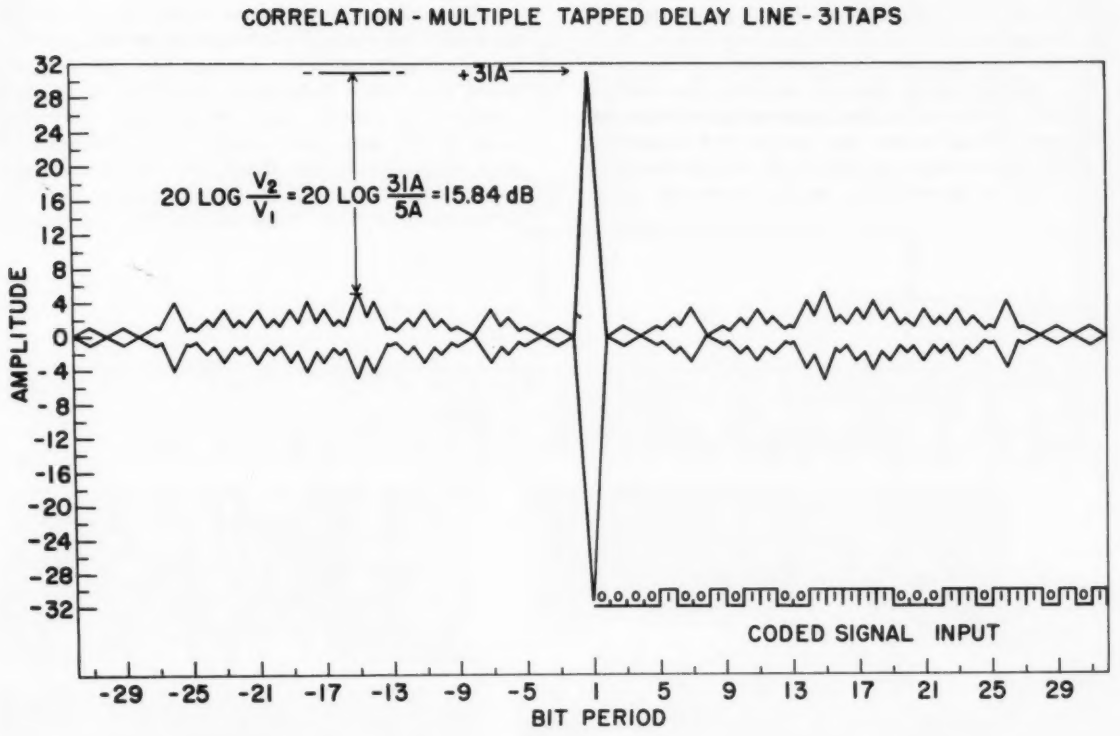


**Figure 2. Theoretical plot of amplitude versus bit period for the correlation of the 31 bit biphase modulated M-sequence.**

In these devices, which were designed to operate either at 70 MHz or 100 HMz center frequency, a digital pulse or information bit is used to generate, by means of an interdigital transducer, an elastic surface wave pulse which propagates on a piezoelectric Y-cut quartz substrate. This propagating pulse has a center frequency of 70 MHz or 100 MHz, depending on the spacing of the lines of the transducer. As the "information bit" propagates along the X-axis of the quartz, it is detected either in phase or out of phase by 31 single pair interdigital transducer taps spaced 100 nsec apart. This spacing corresponds to 7 wavelengths at 70 MHz (or 10 wavelengths at 100 MHz). The sequence gives rise to a biphase modulated pseudo-random code which may be used directly as the synchronization preamble for coordinated multiple access systems, or as the transmitter of information. Six bits of the sequence can be seen in figure 1.

In a communications application, information would be amplified and transmitted to a correlator or decoder (a mirror image of the encoder) fabricated with the same photolithographic master on a matched quartz substrate. The correlation peak and side lobes after rectification of the rf signal are shown in the bottom part of figure 1; thus one distinct output corresponding to the information bit is obtained. The theoretically predicted correlation peak and its side lobes are shown in figure 2. The output of the decoder, as the waveform enters and passes through, consists of a series of 30 sidelobes, one sidelobe per bit period, with amplitude between 0 and 5A. In our case, when bit 1 arrives at tap 31, the tap nearest the input transducer, a signal of -A is obtained from the summed output. One bit-time later, bit 1 is at tap 30 giving an output of A; simultaneously, bit 2 is at tap 31 giving an output of -A, and the net output is 0. Adding and canceling continue until the 31st bit period when the output of all 31 taps are adding in phase, giving an amplitude 31 times A. This is followed with 30 further bit periods with sidelobe amplitudes between 0 and 5A. The theoretical peak to sidelobe ratio was experimentally observed with this device, confirming the accuracy of the photorepeater used in fabricating the photolithographic master.

The information amplitudes, A, add coherently, giving 31A or $(31)^2$P (P is the power of one bit), while the noise adds incoherently, yielding 31P. Thus, signal-to-noise enhancement of 31 is obtained through the encoding-decoding process. This particular aspect of surface wave devices has generated great interest for use in secure

communication, as illustrated in figure 3. In the upper left-hand photograph, the 31 bit, 3.1 μsec-long code is observable above the noise for a 35 volt input pulse to the encoder. The correlation peak and sidelobes observed from the decoder are shown in the upper right. In the bottom photographs, it can be seen that the encoded information, which was buried below the noise level of a transmitter or jammer, can be recovered by passing it through the decoder.

These surface wave devices, which were fabricated on the quartz slab 1 x 0.35 x 0.16 inch shown in figure 4, have the advantages of being compact and lightweight, and having low power dissipation. The 12μm wide chrome-aluminum lines were etched on the quartz substrate by means of the same photolithographic techniques used to make integrated circuits. Hence, the cost of these surface devices, when mass produced, will be comparable to those of integrated circuits. These 10-megabit/sec surface wave

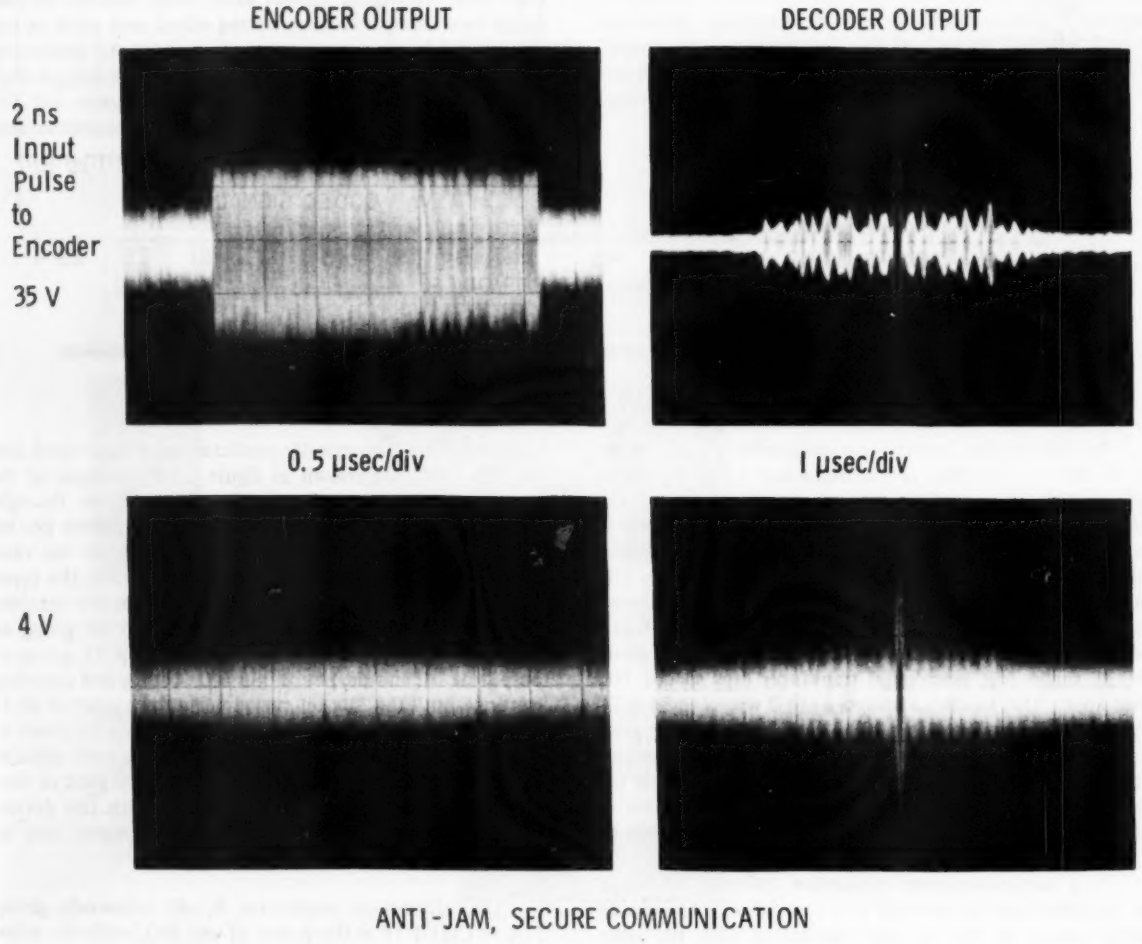


**Figure 3. Surface wave application in anti-jam secure communications.**

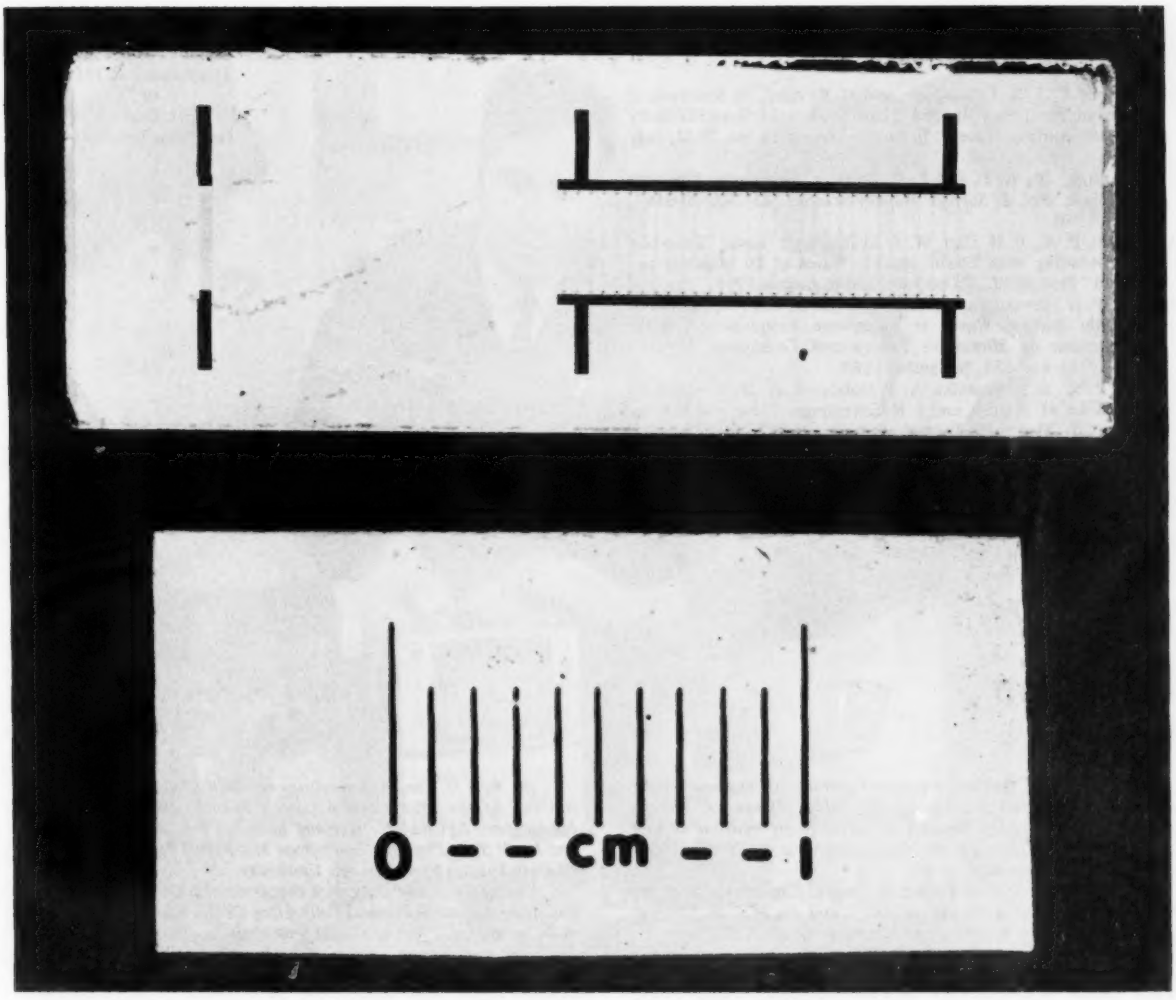


**Figure 4. Multiple tap acoustic surface wave delay line - center frequency 70 MHz.**

devices are generally smaller than integrated circuit devices having comparable bit rates. In addition, the integrated circuit devices require watts of DC power to operate, while the passive surface wave devices require none. The design of these devices requires the extensive compilation of information on piezoelectric coupling, beam steering, and diffraction loss, as summarized in the recently compiled *Microwave Acoustics Handbook* (2) and recent AFCRL research publications (3,4,5).

Recent research of the Microwave Acoustics Branch in pioneering the generation of surface waves at center frequencies as high as 2.5 GHz indicates that it may be possible to fabricate surface wave devices at much higher bit rates than is possible with integrated circuits. These size, speed, and power advantages of surface wave devices make them very attractive for use in satellite communications systems with or without multiple access requirements.

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*Major Peter A. DeVito, a research electronics engineer in the Microwave Acoustics Branch of AFCRL's Microwave Physics Laboratory, is presently engaged in research on multiple tapped surface wave delay lines and their applicability to modern radar and communications systems.*

*Major DeVito received his B.S. in General Engineering from the United States Naval Academy in 1957, and his M.S. in Eletrical Engineering from the University of Pittsburgh in 1966.*

*Earlier experimental research by Major DeVito in varied aspects of injection locking of pulsed magnetrons included controlled pulses, injection ratio, locking bandwidth, phase coded pulses, and long term stability.*

*Mr. William Kearns is an electronic engineer in the Microwave Acoustics Branch, Microwave Physics Laboratory, AFCRL. He received his Associate Degree in Electronic Engineering from Northeastern University in 1955.*

*After serving as an electronic systems instructor for the Air Force during World War II, Mr. Kearns joined AFCRL as an electronic engineer studying microwave antennas. Currently Mr. Kearns is conducting research and development in microphotolithography for fabrication of interdigital transducers on various piezoelectric substrates.*

*Mr. Kearns is a member of IEEE, Electronic Devices Section, and the American Optical Society.*

*Dr. Paul H. Carr, a supervisory research physicist (solid state), is Chief of the Microwave Acoustics Branch, Microwave Physics Laboratory, AFCRL. He received both his B.S. in Physics (1957) and his M.S. in Physics (1961) from M.I.T. In 1966 he received his Ph.D. in Physics from Brandeis University.*

*During his active duty with the Army, Dr. Carr was assigned to the Army Missile Command Calibration Center where he worked on new techniques for the calibtation of accelerometers, optical detectors, and vacuum gauges. Since he joined AFCRL in 1962, he has discovered new nonlinear interaction between microwave acoustic waves, new Raman type photonphonon double-quantum transitions, and has initiated the measurement of the properties of microwave frequency surface waves necessary for the design of devices.*

*Dr. Carr is a member of the American Physical Society, and RESA, and is a Senior Member of the IEEE. He was co-winner of the Marcus D. O'Day Award for the best AFCRL paper published in a scientific journal in 1967. He has published widely in the field of microwave acoustics and has received several patent awards.*

*Technical Sergeant José H. Silva is a research technician in the Microwave Acoustics Branch of AFCRL's Microwave Physics Laboratory where he is primarily responsible for providing high quality, thin metal films, and piezoelectric thin films used in the fabrication of microwave acoustic devices. For this work he received the Air Force Commendation Medal and was named as the Office of Aerospace Research Outstanding Airman of the Year (1970).*

**Examining the acoustic surface wave device used in encoding or decoding binary information are (left to right) Dr. P. H. Carr, Major P. A. DeVito, TSgt J. H. Silva, and Mr. W. J. Kearns.**

# SCIENTIFIC NOTES

## RARE EARTH COBALT MAGNETS

**Materials Physics and Manufacturing Technology Divisions, AFML**

For the past 10 years, AFML has conducted an in-house research program on the nature of binary compounds of a rare earth (yttruim, cerium, praseodymium, or samarium) with one of the transition metals (iron, cobalt, or nickel). Samarium cobalt magnets had properties superior to all others for most applications.

As a result of these efforts, AFML contractors are developing manufacturing methods to improve traveling wave tubes utilizing a samarium cobalt intermetallic compound as the permanent magnet component material. These tubes should be available shortly for producing samarium cobalt magnets in bulk form for other applications.

Samarium cobalt magnets have roughly twice the coercivity and performance and half the weight of platinum cobalt magnets at half the cost. When samarium cobalt magnets were substituted for platinum cobalt magnets in the Hughes 641H traveling wave tube, the following improvements appeared:

(1) A 10% increase in pulse power output.

(2) The duty cycle was doubled, resulting in double the average output power.

(3) A 50% decrease in diameter over the magnet stack.

(4) A 25% decrease in tube weight.

Based upon the data obtained to date and discussions with industry, predictions for samarium cobalt magnets are:

(1) $SmCo_5$ magnets will replace all platinum cobalt magnets, whether in traveling wave tubes or elsewhere.

(2) $SmCo_5$ magnets will replace Alnico IX magnets used in traveling wave tubes.

(3) Microwave tubes using periodic permanent magnet (PPM) stacks will be extended in power output capability, efficiency, and frequency by the use of $SmCo_5$.

(4) $SmCo_5$ magnets can reduce the size and weight of periodic permanent magnet klystrons to permit use of klystron amplifiers in aircraft.

(5) Where a trade-off of reduced weight and volume will merit the inherent additional cost, the size and weight of magnetrons, m-type backward wave oscillators, and crossed field amplifiers can be significantly reduced.

## A NEW VACUUM MICROBALANCE

**Space Physics Laboratory, AFCRL**

A symmetrical-beam torsional ultramicrobalance system has been designed and developed to monitor mass changes in the area of $10^{-7}$ to $10^{-9}$ gram of samples weighing some hundred milligrams. The range and the sensitivity of the balance are variable and can be continuously changed by external adjustment. Mass changes of the sample are compensated by the pressure of light. The force exerted by a light beam is measured and calibrated with a radiometer—a vertically suspended torsional beam balance of high sensitivity. This method of compensation is not subject to various effects such as the stray magnetic fields that interfere with and limit many generally used methods. The operation is fully automatic.

The balance is operated inside a bakeable Varian ultra-high vacuum chamber with a vacuum capability of $10^{-11}$ torr, permitting adsorption, absorption, desorption, sputtering, and decomposition studies. The rate of detectable mass change is on the order of $10^{-10}$ gram per second and less. The balance could be used to measure small perturbing forces, as well as mass changes.

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## VUILLEUMIER CYCLE CRYOGENIC COOLERS DEMONSTRATE A NEW ERA IN AIRCRAFT RELIABILITY

### Air Force Flight Dynamics Laboratory

Many aircraft systems, such as reconnaissance, surveillance, fire control, and guidance, require cryogenic temperatures for equipment operation. Currently available cooling systems are subject to undesirable vibration and noise; frequent service is necessary. The cost is high in terms of time, money, and mission effectiveness.

The Air Force Flight Dynamics Laboratory has now demonstrated the possibility of producing closed-cycle refrigeration systems that will provide a new level of performance at reduced cost of maintenance. A Vuilleumier (VM) cryogenic cooler under development has completed more than 1000 hours of trouble-free operation in its first endurance test. The test schedule demonstrated a life potential at least double that of coolers presently in service.

In addition to evidencing new technical capabilities, this program provides reliable cooling systems for use in flight-testing two new infrared systems: a Modified Advanced Forward-Looking Infrared (MAFLIR) sensor and an Advanced Low Altitude Infrared Scanner (ALAIRS), designated the AAS-27, both under development by the Air Force Avionics Laboratory.

Two identical VM coolers were configured and fabricated for the MAFLIR sensor. One unit, undergoing comprehensive test and evaluation by the AFFDL, has been operated for more than 400 hours without maintenance. The second unit, delivered to the Hughes Aircraft Company in April 1970, was mated with a MAFLIR sensor which had previously been cooled by a Stirling cycle refrigerator. Noise and microphonics produced by the Stirling cooler detracted from the available military capability of the total system. Installation of the VM refrigerator eliminated the microphonics problem. Flight tests of this system began in November 1970. Since the integration of the cooler with the MAFLIR, it has been operated for 500 maintenance-free hours. The VM cooler provides a larger margin of safety in cooling capacity, higher reliability, and reduced maintenance.

Two VM coolers were also fabricated for the ALAIRS system. One is being delivered to the ALAIRS manufacturer, Honeywell Radiation Center, for integration and flight test; the other, endurance tested by the AFFDL, has achieved 1185 hours of intermittent operation without maintenance or loss of performance. This type of reliability represents the beginning of a new era in miniature closed-cycle refrigeration for military aircraft.

It is now apparent that closed-cycle refrigeration systems can be designed and produced with cost of ownership decreased by 50% to 75%. If this type of cryogenic cooler realizes its full potential, the savings accruing from its operational use could exceed $50 million per year.

Contact: AFFDL/FE

## LASER RESEARCH

### Air Force Rocket Propulsion Laboratory

Because of their high-energy potential, scientists at the Rocket Propulsion Laboratory have been interested for a number of years in hydrogen and fluorine (H-F) rocket propellants. While in the process of studying the kinetic properties of hydrogen-fluorine and hydrogen-oxygen difluoride in a shock tube experiment, laboratory researchers observed unusual light emission from newly formed propellant molecules. After H-F was shown to lase by other laboratories, and a potential was demonstrated, AFRPL scientists started a series of investigations and demonstrations which may prove vital in the development of useful chemical laser devices.

The average lifetime of the excited hydrogen-fluorine molecule is extremely short, on the order of one-millionth of a second, a fact which may have important bearing on the application of the H-F chemical laser. Rocket Propulsion Laboratory research has been aimed at demonstrating the feasibility of a practical chemical combustion laser device. The Laboratory is now conducting a new series of kinetic studies of the processes involved in the lasing media—the excitation and de-excitation processes in H-F molecules—which could lead to more efficient and practical devices.

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## IRRADIATION DEFECTS AND THE ELECTRICAL QUALITY OF ION IMPLANTED SILICON

**Solid State Sciences Laboratory, AFCRL**

Ion implantation is being investigated as a means of introducing specific dopant impurities into silicon and other semiconductors. Implantation involves the ionization of the desired dopant atoms, their acceleration by a high electric field, and their penetration into the semiconductor by making the semiconductor the target for the ion beam. With the growing need for greater control and versatility in semiconductor doping, this technique could develop into a highly significant technology for the manufacture of both discrete devices and integrated circuits.

Implantation, however, is a damaging process. Despite the fact that electron microscopy has established that silicon crystallinity can be regained through annealing, the full potentialities of the process will only be realized if the electrical characteristics of the material are not impaired and are understood.

Recently, D. Eirug Davies and Sven A. Roosild conducted an extensive electrical evaluation of ion irradiated silicon in an in-house program at AFCRL. The important finding of this study was that when the dose is restricted so that the implanted layer becomes the low doped side of a p-n junction, the damage does not inhibit the annealing recovery of the device electrical parameter, minority carrier lifetime, from reaching levels deemed adequate. At higher doses leading to the creation of amorphous layers, it is more difficult to remove the defects, but lifetime itself is then no longer an important device design parameter.

Another finding of the study was that the manner in which the defects anneal, and the anticipated accompanying compensating properties, account for many of the hitherto unexplained features involved in conductance annealing. This result shows in a positive way how damage, when it is deliberately employed, can be used for enhancing conductance annealing - an important aspect for successful device operation.

Another important result of this investigation was the finding of a means for controlling minority carrier lifetime. As the lifetime is still damage-dependent after annealing beyond the requirements for eliminating cluster disorder, it was established that point defects are residual after lattice reordering. The lifetime data provide the most striking evidence to date that such damage is induced by ion implantation. The presence of these defects, and their stability extending to above normal device operating temperatures, suggested a method for their utilization as a means for controlling minority carrier lifetime merely by selecting the proper annealing conditions for improving the devices. A patent disclosure on this method has been written.

This last result is of particular importance in the design of high-frequency and radiation-hardened transistors, where only low minority carrier lifetimes in the active regions of the devices are essential. Lifetime "killing" is presently accomplished in the gold doping of silicon wafers by diffusing, after all other processing steps have been performed. Since this device processing step is the most difficult one to control, losses are necessarily high on wafers of devices that are almost finished - a costly failure.

The results of this investigation, which show the means for eliminating electrically active defects on the one hand or utilizing them for lifetime "killing" on the other hand, represent important steps in advancing the technology of ion implantation toward the goal of device production.

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## HIGH RESOLUTION CHEMICAL IONIZATION MASS SPECTROSCOPY

**W. R. Powell, AFML**

The University of Utah, under contract to the Analytical Branch of the Materials Physics Division, is developing a high resolution chemical ionization mass spectroscopy system. By modifying a commercial high resolution mass spectrometer, the University has devised a system for high pressure mass spectrometry that uses a source pressure of 1 torr as compared with the usual analytical pressures of $10^{-5}$ to $10^{-4}$ torr. Pilot studies have shown that frequently chemical ionization mass spectrometry is more sensitive than electron impact mass spectrometry; it has a resolving power of one part in 57,000, which equals or surpasses that of electron impact instruments.

Through a systematic study of various chemical classes using different reagent gases such as methane, propane, and isobutane, the project is now establishing a quantitative analytical technique for high precision control of the amount of energy deposited in the reacting molecule. Using this method, the University has detected a group of peptides in the 10 to 70 nanogram range, a result that should produce strong incentives for further research.

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## DESIGN AND SYNTHESIS OF MATERIALS FOR LASERS

**Air Force Office of Scientific Research**

The development of a continuously tunable laser, able to emit coherent light through a range of frequencies, is a major Air Force research objective. Infrared laser systems are of particular interest because of their low eye hazard, partial tunability, and special applicability to covert communications. However, most infrared dye laser materials have disadvantages such as poor photochemical stability, early quenching, and low power output.

AFOSR has supported the efforts of Professor Glenn A. Crosby at Washington State University to provide basic knowledge of the structures and dynamics of luminescent materials having potential applications to lasers and other devices. He recently developed a sophisticated (and general) quantum-mechanical model of excited states and their interactions with electric and magnetic fields in large classes of potential lasing materials. Professor Crosby regards this model, which correlates the extensive experimental work of his group, as a breakthrough in this area of spectroscopy. This new understanding of the general nature of charge-transfer excited states has enabled the design of new materials with preselected optical and magnetic properties. Synthesis and testing of a number of these materials has started. This important capability, to increase quantum yields, to decrease lifetimes, and to shift frequencies, is a major step forward that has far-reaching implications for designing electro-optical materials needed in highly specialized tasks. Through his consulting activities, Professor Crosby has stimulated the interest of industry and the Air Force in infrared dye laser materials to fulfill specific needs for secure communications, tracking, targeting, and laser countermeasures.

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## GEODETIC APPLICATION OF LONG BASE LINE INTERFEROMETRY

**AFSC Detachment 37, Office of Research Analysis**

Pulsars, the recently discovered celestial radio sources, can be used to determine the distance between two radio telescope stations on or above the surface of the earth. Two basic approaches were tried to investigate the accuracies achievable with this new method of obtaining geodetic information. One approach was to observe one pulsar over a long period of time; the second, and preferable approach, was to make one observation on each of three different pulsars.

The study showed that if the accuracies in measuring the pulsar declination and difference in signal arrival times are extremely high ($10^{-7}$ radian and $10^{-9}$ sec, respectively), the accuracy in distance is limited by the error in the speed of light, the presently accepted value of which is 300 m/sec. For example, for a distance of 500 km, the accuracy limit, due to the uncertainty of the speed of light would be 5 meters.

The current state-of-the-art permits measuring pulsar declination and signal arrival times to $10^{-5}$ radian and $10^{-7}$ sec, respectively. By using pulsars, a distance of 5200 km can be determined within an error of 100 meters.

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## A MODEL FOR EVALUATING THE UTILITY OF FORECASTING NATURAL ENVIRONMENTAL PHENOMENA

**Richard H. Anderson**
**Hans J. Richter**
**AFSC Detachment 37, Office of Research Analysis**

A probabilistic model was developed to quantify the utility of procedures for forecasting phenomena which threaten the success of a mission. The model, which is unique and has many Air Force applications, was used to determine the requirements of forecasting certain types of solar activity endangering the success of aerospace missions.

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# READERS INTERCHANGE

# Research Advances

### Electrofluid Dynamic Energy Conversion

*Development:* EFD energy conversion is a process that converts heat energy directly into electrical power through the use of fluid dynamic energy. The process produces low current densities and very high voltages, with no moving parts in a power class from kilowatts to megawatts. The heat source could be isotope fuel or nuclear.

*Applications:* Self-contained EFD generators will have major applications to reliable and continuous power generation at unattended locations over long periods of time, e.g. to space vehicles and remote radar sites.

Research has been conducted in the areas of similarity and scaling laws, charged colloid production, voltage scheduling, geometric effects, fluid dynamic energy conversion, overall thermo-electric cycles, and two-fluid, two phase, supersonic-subsonic gas flows. To date, sufficient knowledge has been accumulated to support the development of a low capital cost, open cycle, multi-kilowatt generator that would be suitable for applications where low efficiency is acceptable, e.g., intermittent, short interval operation. Two other characteristics of this generator would be its infinite impedance and suitability for parallel staging.

Project No. 7116 RA ARL 71-6

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### Catalyst for Gaseous Hydrocarbon Reactions

*Development and Applications:* Work in the area of d-orbital bonded molecules has shown that the solid $LaCo0_3$ may be an efficient economical replacement for plantinum catalysts in applications such as fuel cells and anti-pollution devices for engine exhausts.

Data were taken on a gaseous mixture of C-2 butane in excess $H_2$, and the production of n-butane, olefinic isomers, and methane, ethane, propane, and heavier hydrocarbons followed as a function of temperature. At the lowest temperature used (130°C), 30% butane was given in 1 to 2 seconds of contact time. The $LaCo0_3$ powder used had a surface area too low to measure by microscopic examination. This limited data suggests that the $LaCo0_3$ is intensely active.

Project No. 9538 RA AFOSR 71-1

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### Transient Analysis and Optimal Design of Nonlinear Dynamic Circuits

*Development:* Mathematical research related to efficient computer analysis and optimization of electrical networks has resulted in the development of an efficient program for the transient analysis and optimal design of nonlinear dynamic circuits. The program was developed as a research tool to investigate various numerical aspects of such analysis and design.

*Applications:* In addition to being a valuable investigative tool for research activities, this program could be modified for application to specific circuit design and optimization problems. The program also has potential application to Air Force on-the-job or training school activities such as in the area of electronic maintenance.

Project No. 9749 RA AFOSR 71-2

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### Configuration Optimization of a Class of Hypersonic Cruise Vehicles

*Development:* A computer study determined basic configuration characteristics and performance trends of hypersonic cruise vehicles. Forces acting on the vehicle were determined by analysis of the surrounding flow field; thus, interaction between the aerodynamic and propulsive flow fields was accounted for in a fundamental manner. Optimization was performed using several multivariable search techniques of which the nongradient methods were found to be most effective. Results of the study showed, for the geometrical class of vehicles investigated, that approximately three-fourths of the total lift is provided directly from the propulsion system. The results also indicated that Breguet range factors on the order of 10,000 nautical miles are attainable by vehicles which cruise in the Mach 8 to 12 speed regime.

*Application:* To programs dealing with vehicle design.

Project No. 7064 RA ARL 71-9

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### Optical Probing Data Reduction Program

*Development:* A computer program (written in Fortran IV) has been developed by the Plasma Physics Research Laboratory of ARL to determine temperatures and densities of various atomic and molecular species in self-absorbing sources. The program reduces the side-on emitted intensity and transmission profiles of volume emission and absorption coefficients in rotationally symmetric sources. It is based on an analytic solution to the radiation transfer equation in self-absorbing sources. The basic input data are the profiles of emitted and/or transmitted radiation intensity observed along chords perpendicular to the symmetry axis. The program can also be used to obtain either the volume emission coefficient or absorption coefficient when the other is negligible, i.e., optically thin sources or purely absorbing sources.

*Application:* This program can be used by any laboratory desirous of studying rotationally symmetric sources with spatial resolution, e.g., arcs, arc jets, nozzles.

In addition to the above program (analytic description plus program and users manual), a detailed description of an appropriate optical scanning and electronic data acquisition system is available.

Project No. 7073 RA ARL 71-8

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### Type Conversion by Ion Implantation

*Development:* By implanting Li-ions into high conductivity n-type ZnSe crystals, p-type conduction was obtained and a p-n junction was thereby produced. Diodes fabricated from implanted material showed good rectification, photovoltaic effect, and low-voltage electroluminescence.

The achievement of type conversion by ion implantation should accelerate progress toward the attainment of efficient, low-voltage p-n junction light-emitting diodes of II-VI compounds. It is generally known that the Zn and Cd II-VI compounds, with the exception of CdTe, cannot be easily produced in both p- and n-type of growth or thermal diffusion techniques. Because of this difficulty with the II-VI class of compounds, efficient, light-emitting p-n junction diodes have not previously been produced. The II-VI compounds all have direct band gaps, are luminescent materials of high efficiency, and are the best prospective host crystal materials for visible light emission. These diodes are low-powered and can be made very small in size. Injection laser action is also envisioned from these diodes.

*Applications:* (1) Efficient, low-powered visible light indicators, (2) optical displays, and (3) optical data transmission.

Project No. 7885 RA ARL 71-5

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### Oxidation of Ni-Base Alloys Containing Additions of Cr, Al, and/or Y

*Development:* Oxidation studies of Ni-base alloys have been carried out over the temperature range 800° to 1300°C under natural convection and forced convection conditions in either air or pure oxygen at pressures from .001 to 1 atmosphere. The Cr and Al contents in the alloys varied over the ranges 4-14 w/o and 3-9 w/o, respectively. The results have shown that the alloy exhibiting the best oxidation resistance is Ni-9Cr-6Al, due to its formation of a protective $\alpha$ - $Al_2O_3$ scale at all temperatures investigated. The Cr addition in the alloy enhances the diffusion of Al to the alloy surface and stabilized the $\alpha$ - $Al_2O_3$ to room temperature. However, the oxide scales easily spalled off during thermal cycling. As a result, small additions of yttrium ($<$ 1 w/o) were added. The results have shown that Y additions do reduce the oxidation rate and greatly improve the oxide adherence under cyclic conditions. The optimum Y content is approximately 0.1 to 0.2 w/o. The effect of the yttrium addition is proposed to be associated with the formation of an alloy substructure.

These results clearly define a composition for the quatenary alloy system, Ni-Cr-Al-Y, which shows excellent oxidation resistance at high temperatures and excellent adherence of the oxide under severe cyclic conditions. The fact that the oxide formed is $Al_2O_3$ eliminates the problem of the vaporization loss encountered in alloys protected with a $Cr_2O_3$ scale. In addition, since there are no intermetallic compounds found in the alloy at these low yttrium concentrations, there is a high probability that it will be mechanically workable. This alloy represents a breakthrough in high temperature oxidation resistant alloys in that it forms a very adherent scale of highly stable, oxidation retarding $Al_2O_3$.

*Applications:* Can be used extensively under conditions of high temperature oxidizing atmospheres, where the super alloys are now being used.

RA ARL 71-10

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# Research Needs

**Aeromedical Assessment of Phase Dilution Aviator's Oxygen Concept**

*Problem:* New self-contained aviator's oxygen generators require specific respiration physiology data on oxygen usage for integration of oxygen generators with the aviator's oxygen needs. Oxygen generators are available with acceptable power penalties and heat rejection, but with limited oxygen output. This output fills the basic physiologic oxygen needs, but does not meet emergency oxygen needs and prescribed safety margins. Under certain operational conditions, present oxygen dilution systems provide excess oxygen to the aviator, thereby resulting in oxygen generator devices that are over-designed with large power penalties.

*Area of Need:* Oxygen regulators and masks in the phase dilution concept provide an oxygen saving concept, but aeromedical data on respiration physiology are needed to determine the acceptable oxygen usage rates and concentrations to the aviator's mask. These data are also needed to attain optimum integration of the aviator's oxygen equipment with the onboard oxygen generator capacity of future aircraft.

RN AFFDL-71-1

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**Power Flow Coupling Coefficients for Statistical Energy Analysis of Vibrating Systems**

*Problem*: A method of statistical energy analysis of vibrating systems was developed to predict the high frequency response of complex multimodal structures. Statistical energy analysis is based on average quantities rather than on the unaveraged quantities used in classical methods. The main premise of the statistical energy analysis of vibrating systems is that the time averaged power flow from one elastic system to another is proportional to the difference between the time averaged kinetic energies of the two systems, the constant of proportionality being known as the power flow coupling coefficient. The inability to determine these coefficients analytically has limited the practical application of the statistical energy method in predicting the high frequency response of realistic aircraft structures. Approximations of the power flow coupling coefficients have been analytically determined for sound-to-structure interfaces, but only for a few structure-to-structure interfaces in very simple configurations.

*Area of Need:* Research is needed to develop techniques for the prediction of power flow coupling coefficients for the more common types of aircraft structures.

RN AFFDL-71-4

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**Infrared Measurements of Aerodynamic Heating**

*Problem:* The Air Force is currently developing, fabricating, and demonstrating an infrared scanning system that will measure heat transfer to complex high-speed military aircraft configurations. The effects of model surface emissivity, reflectivity, view angles resulting from complex geometry, attenuation of emitted radiation due to thermal gradients in the wind tunnel air stream, etc., on the difference between true surface gradients and indicated gradients must be known in order to solve the heat conduction equation used to obtain heating rates.

*Area of Need:* Research is needed to determine the significant parameters affecting the interpretation of aerodynamic heat transfer data obtained with an infrared scanner. More precise interpretation of the data is also needed.

RN AFFDL 71-5

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### Transonic Unsteady Aerodynamic Prediction Method

*Problem:* Analytical prediction methods for unsteady aerodynamic forces on thin wings and slender bodies at small angles of attack and small local body slopes are available within the limitations of linear potential flow theory for Mach numbers less than 0.85 or greater than about 1.2. For Mach numbers between 0.85 and 1.2, the nonlinear flow equations have deterred general solutions.

Numerical methods have been developed based on linearized solutions to transonic flow, but are only applicable at high oscillatory frequencies and for highly swept lifting surfaces. Both the iterative method of solving nonlinear equations by parametric differentiation and the use of local acoustic properties in linear analysis have been investigated, but have not been fully developed for unsteady flow calculations.

*Area of Need:* The need exists for the development of improved methods of predicting unsteady aerodynamic forces on air vehicles in the critical transonic flight regime. These unsteady aerodynamic forces are required to determine dynamic response and flutter characteristics of the air vehicle which are an integral part of the overall vehicle design for safe and efficient flight.

RN AFFDL-71-7

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### Fracture Mechanics of Advanced Filamentary Composite Structures

*Problem:* Advanced composites fail in a wide variety of modes. When cracks grow in a laminate, they normally proceed in directions that are dependent on fiber direction as well as load direction. The analysis methods developed for metals have been of little value in describing the behavior of composites which are anisotropic and nonhomogeneous.

*Area of Need:* Development of a fracture mechanics analysis is needed to predict the life and strength of damaged multidirectional laminates.

RN AFFDL 71-10

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### Automated Mesh Generation Techniques for Structural Shell Analysis

*Problem:* Current methods (e.g. a nonlinear collapse analysis of general shells) require that a two-dimensional finite difference grid be applied to a general curvalinear surface having irregular boundaries. Generation of input data (x, y, z coordinate data) for the surface is quite tedious and time consuming and requires extensive modification to be done by hand before the analysis can be performed. Present capability does permit specification, for common geometrics (such as spheres, cones, and cylinders), of the fineness of mesh desired to produce a uniformly spaced grid and to have the input data generated automatically. However, for complex irregular shells, hand generation of data is still required.

*Area of Need:* An automated mesh generation technique must be developed to produce the mathematical model required for discrete numerical analysis of complex shell-type structures.

RN AFFDL-71-12

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### High Energy Endothermic Chemical-Kinetic Reactions for Use as Long Term Heat Sinks

*Problem:* In space and in certain high altitude high speed aircraft, it is difficult to dispose of waste thermal energy. In a satellite, on a long term basis, waste thermal energy can be disposed of economically only by radiation to deep space. This requires a typical penalty of one pound per square foot of radiator surface. Similarly, in high speed aircraft, in which ram air temperatures are so high that expendable change of phase heat sink must be carried, current systems are limited to latent heat of evaporation of available fluids, resulting in excessive weight and size penalties.

*Area of Research:* Some type of controllable reaction, probably involving a chemical change in some material followed by the emission of matter at high kinetic energy, could conceivably provide a net heat sink representing low initial mass when sized either for the probable length of a mission or for vehicle life. Research is needed to determine if some reaction, such as a chemical-kinetic transition, could be used as a long term heat sink in lieu of the large and heavy steady state heat rejection systems now in use.

RN AFFDL-71-15

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## Method of Correlating the Wake Shape of a Statically Operating Propeller or Rotor With Readily Available Blade Geometry Data

*Problem:* There are no available methods to relate the usually known propeller (or rotor) geometrical characteristics to the shape of the wake generated by the propeller when operating statically. Data on this wake shape is essential for use as inputs to advanced static performance prediction methods currently being developed for V/STOL and STOL propulsion.

*Background:* Predicting the detailed performance of propellers or rotors is inherently more difficult than that for fixed wings in which the wake trails away from the wing to downstream infinity. The problem is particularly severe in the static case, since the absence of a free stream velocity requires that the wake geometry be determined solely by the blade rotation and the induced velocity field of the propeller and its wake system. This causes severe wake distortion to occur in the immediate vicinity of the blades; any rigorous analysis of the static performance problem must accurately account for the strong influence on performance of this wake distortion.

*State-of-the-Art:* Currently, there are two approaches to the problem of treating the influence of wake distortion. The first method involves a rigorous numerical solution for the distribution of vorticity throughout the wake (2,3). Since the wake is made up of many vortex segments, each of which must be independently positioned according to blade loading (which is also unknown), an iterative solution is required and calculations rapidly approach the millions. Therefore, the computation cost of a single point escalates until the method becomes unusable for design purposes.

The second approach is one in which the distorted wake geometry becomes an input to the performance prediction program (4). This technique requires, obviously, that the wake shape be known. At present, the only available method of determining this shape is to build a model propeller and take smoke pictures of the wake. While this method yields satisfactory results, there has been no attempt to correlate and generalize this type of data. It would be highly desirable to separate the performance prediction techniques from direct experimental measurements by making available a method to predict wake shape from the physical characteristics of the propeller.

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(3) Landgrebe, A. J., "An Analytical Method for Predicting Rotor Wake Geometry, AIAA Paper 69-196. Presented at the AIAA/AHS VTOL Research Design and Operations Meeting, February 17-19, 1969.
(4) Hamilton-Standard Division, United Aircraft Corporation, "Prescribed Wake Static Propeller Method," work conducted by Hamilton-Standard under Air Force Contract F33615-69-C-1720.

RN AFAPL 71-2

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## Higher Efficiency Solar Cells Through Improvements in the Silcon Starting Material

*Problem:* The increasing electrical power requirements of satellite systems have resulted in the need for the development of multi-kilowatt solar array power systems. The current approach is to use very large array configurations to provide the required power. Unfortunately, very large arrays tend to accentuate the problems of array deployment, packaging, and flight dynamics. A second and more attractive approach to this problem would be to increase the efficiency of solar cells in order to provide the high levels of power with smaller arrays. In addition, overall improvements in solar array power density and specific weight would be realized.

*State-of-the-Art:* Present operational efficiencies of space qualified solar cells lie in the 10.5% to 11.0% range. Although the maximum theoretical efficiency of silicon solar cells is 24%, no cells have been quantitatively manufactured with efficiencies greater than 12%.

*Background:* Prior attempts to increase cell efficiency have not been successful. A multilayer cell configuration was investigated; it did not even meet present cell efficiencies. Lithium doped cells with efficiencies equal to standard cells can be fabricated. New diffusion techniques promise efficiencies in the 12.5% regime, but this area has yet to be fully investigated. At present, standard silicon cells with efficiencies near 14% have been fabricated under laboratory conditions. By improving the diffusion lengths and lowering the silicon resistivity, high efficiency silicon solar cells can be manufactured. These developments would constitute an improvement in the silicon starting material.

*References:* Solar cell efficiency improvements have been

*References:* Solar cell efficiency improvements have been conducted under the following programs:
(1) F33615-68-C-1189, Westinghouse Electric Corp., "Silicon Cell Lifetime and Efficiency Improvement."
(2) F33615-68-C-1198, Heliotek, "Lithium Doped Hardened Solar Cell Optimization."
(3) F33615-70-C-1491, Ion Physics Corp., "Long-Life Hardened Lithium Doped Silicon Solar Cells."

RN AFAPL 71-4

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## High Energy Density Electrochemical Power Sources for Electronic Countermeasure Devices

*Problem:* Technology needs in the area of expendable electronic countermeasures for aircraft are demanding power sources capable of operating in extreme environments (e.g., -65°, +165°F, 100,000 feet altitude, shock, vibration) and yield 5 watt-hour/$in^3$ to 8 watt-hour/$in^3$. Also, these power sources must have inactive life (storage life) exceeding 8 years and be low cost items (< $10/unit). Existing technology (i.e., chemically heated zinc-silver oxide reserve battery) yields 1.2 watt-hour/$in^3$ over the specified environment. Intensified research on high energy battery systems such as molten salt electrolyte systems and heated reserve lithium nonaqueous systems is required.

*State-of-the-Art:* Extremely limited data/knowledge is available on the characteristics of total cells and batteries of the molten slat electrolyte variety as applied to electronic countermeasure devices. Specifically, basic materials characterization and compatabilities investigations are required for the following: (a) pyrotechnic materials for rapid heating, (b) electrical insulators, (c) cell/battery sealants, (d) electrical contactors, and (e) cell case materials. Items "a" apply to the molten salt electrolyte/electrode environment.

*Background:* It is estimated that 40% of the basic knowledge of the electrochemical behavior of the more promising combinations of molten salt electrolyte/electrodes such as lithium-selenium, lithium-sulfur, and lithium-tellurium is known. Data over extended temperature ranges and various material compositions are needed. Measurements of fundamental phenomena associated with these battery systems are also needed.

*References:*

(1) ASD-TN-71-140, "Power Sources for ECM Expendables."
(2) Contracts F33615-69-C-1759 and F33615-69-C-1760, "Chemically Heated Silver Oxide Battery."

RN AFAPL 71-5

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## Low Cost Fuel Cell Electrodes for Operation on Propellant Grade Reactants

*Problem:* Present day hydrogen-oxygen primary fuel cells require ultra-pure reactants to achieve uniform individual cell performance, high efficiency, and long life operation (greater than 60 days) within typical spacecraft voltage range requirements. The purity requirement greatly complicates the spacecraft system, since both ultra-clean cryogenic reactant storage tanks and extremely clean ground servicing equipment at the launch site must be provided.

*State-of-the-Art:* Space qualified fuel cell systems presently operate on 99.95% to 99.99% pure reactants and utilize costly noble metal catalysts. Periodic purging of the fuel cell with about 3%-5% excess reactant is required to flush from the system various reactant impurities such as hydrocarbons, CO, $CO_2$, and inert gases (helium, argon, nitrogen) which accumulate in the porous electrodes and result in loss of efficiency. Hence, successful development of high efficiency, non-noble metal catalyst hydrogen and oxygen electrodes capable of operation on propellant grade reactants would significantly decrease the complexity and cost of future spacecraft/launch support systems.

*Background:* Considerable effort has been expended by the Air Force, NASA, and fuel cell manufacturers to develop improved fuel cell electrodes; however, little attention has been given to the development of electrodes specifically designed to operate on propellant grade reactants. In general, cost has been of secondary importance.

*References:*

(1) "High Performance Light-Weight Electrodes for Hydrogen-Oxygen Fuel Cells," NASA-CR-1216, December 1968.
(2) "High Performance Fuel Cell," AFAPL-TR-70-42, June 1970.
(3) NASA Contract 7-574, "Advanced Fuel Cell Catalysts," Pennsylvania Research Association, Inc.

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## Combustion Processes in Airbreathing Engines

*Problem:* A need exists for additional understanding of the fundamental physical, chemical, fluid dynamic, and aerothermodynamic processes associated with subsonic and supersonic combustion phenomena. Such knowledge is needed to establish realistic design criteria for highly efficient, compact, and stable combustors for advanced airbreathing engines capable of operating over wide ranges of flight speed and altitude, including the hypersonic regime. Specific areas requiring particular attention are listed below.

1. Improving the combustion efficiency of solid boron fuels at low pressures ($\alpha$1 atmos).
2. Decreasing ignition and reaction times by utilizing promoters, fuel blends, staged combustion, and/or photochemical techniques.
3. Improving flame stabilization techniques for conditions below the auto-ignition temperature; e.g. sustain combustion in hydrocarbon fuels in supersonic streams without continuous pilot flames.
4. Understanding the gas dynamics of supersonic heat addition in various shaped ducts including divergent channels with angles $> 1.5°$, thermal compression effects, and interaction of shock waves with the heat addition process.

5. Analyzing fuel injection and mixing processes under conditions of adverse pressure gradient, reacting flows, and with initial turbulence and/or swirl. Consideration of two-phase flow for liquid and solid particle fuels.

*Background:* With greater emphasis being placed on nearer term missile systems, high density storable fuels, in addition to gaseous hydrogen fuel, are now receiving consideration for high speed air-breathing propulsion systems. As a result, some of the gas-to-gas interaction phenomena must now be extended to include liquid and/or solid particle-to-gas processes. Recent research efforts have already been initiated in these areas and should be continued.

*References:*


(1) Abstracts - Sixth AFOSR Combined Contractors Meeting on Combustion Dynamics, June 1970.

(2) "Combustion of Boron Particles at Atmospheric Pressure," Macek and Semple, *Combustion Science and Technology*, Vol. I, No. 3, 1969.

(3) "Ignition of Subatmospheric Gaseous Fuel-Oxidant Mixtures by Ultraviolet Irradiation," N. Levy and A. Cerkanowiez, *AIAA Paper 69-88.*

(4) "Combustion of Liquid Hydrocarbons in a High Speed Air Stream," Edelman, Schmotolocha and Slutsky, *AIAA Paper 70-88.*

(5) "The Interaction of Shock Waves and Heat Addition in the Design of Supersonic Combustors," F. Billig and G. Dugger, *Proc. Twelfth Symposium on Combustion*, 1968.

(6) "Analysis of Fluid Dynamics of Supersonic Combustion Process Controlled by Mixing," Ferri and Fox, *Proc. Twelfth Symposium on Combustion*, 1968.

(7) "Vortex Mixing for Supersonic Combustion," Swithenbank and Chigier, *Proc. Twelfth Symposium on Combustion*, 1968.


RN AFAPL 71-18


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### Prediction of Near Field Noise of Supersonic Jets

*Problem.* Structures close (including the inductive near field) to supersonic jets are subjected to intense acoustic and pseudo-acoustic loads generated by multiple sources associated with supersonic exhaust flow. These loads can result in structural fatigue failures. To avoid these failures, the structure is often overdesigned, primarily due to the unknown acoustic loads. Therefore, it is necessary to define the intensity, spectral content, and cross spectral density of the acoustic loads in order to optimize and insure reliable structural designs.

*State-of-the-Art.* At present there is no adequate theory for predicting the jet exhaust noise from supersonic jets; however, there have been a number of investigations in which the presence of sources of noise such as turbulent shear layers, turbulent eddies, and Mach radiation have been identified. Prediction methods have been developed for supersonic jet noise, relating measured noise to exit nozzle parameters. These methods do not define the mechanisms, but merely relate measured data to nozzle conditions. Consequently, care must be taken in applying the results outside the range of the experiments. The methodology derived from this type of program has generally been limited to the variation of overall noise, with only limited application to the spectral content. No known results are available relating the cross spectral density to the nozzle or flow parameters.

*Background:* The individual sources associated with supersonic jets have been investigated. These stuides have concentrated on the radiated noise and have not considered the acoustic loading of structures located in the near field. This work is well summarized in NASA SP-207, "Basic Aerodynamic Noise Research," which also includes comprehensive bibliographies of supersonic jet noise in the various contributions.

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### Improved Lubricant Pumpability at Low Temperatures

*Problem:* To determine how to make turbine engine lubricants more pumpable at low temperatures without sacrificing desirable high temperature properties.

*State-of-the-Art:* The current standard Air Force turbine engine lubricant is MIL-L-7808 which has a usable temperature range capability of -65°F to +300°F. The proposed MIL-L-27502 will have a temperature range capability of -40°F to +425°F. The most practical high temperature turbine engine lubricant known to date, polyphenyl ether [bis (phenoxyphenoxy) benzene] has a 575°F capability, but its +40°F pour point restricts its extensive use.

*Background:* Air Force turbine engine designs are continually requiring lubricants possessing higher temperature capability. This trend has dictated a corresponding trend toward the formulation of lubricants possessing lower volatility, higher viscosity, and greater stability at higher operating temperatures. Unfortunately, this trend generally dictates the use of higher molecular weight lubricants which, based on existing technology, creates serious low temperature pumpability problems. An undesirable solution to this problem is the use of demand-type lubricant dilution techniques. A far better solution is to determine how lubricants can be made more pumpable without sacrificing other desirable and necessary properties.

*References:*


(1) Mosier, S. A. and M. L. Johnson, "The Influence of Lubricants on Turbine Engine Design," *AFAPL-TR-70-9*, April 1970.

(2) Sumey, I. E., T. E. Russell, D. B. Hester, et. al., "The Influence of Lubricants on Turbine Engine Design," *AFAPL-TR-70-54*, September 1970.


RN AFAPL 71-19


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## Fundamental Parameters Affecting Foaming Characteristics of Lubricants

*Problem:* Excessive foaming or aeration in the lubrication system of a turbine engine or transmission can result in a decrease in lubricant flow to bearings, gears, and seals, causing excessive heat generation and subsequent failure. Foaming can also result in loss of oil through the breather system of an engine if sufficient volume is not available in the oil tank for foam build-up and collapse.

*State-of-the-Art:* All tests currently used for measuring the foaming characteristics of lubricants are empirical in nature; they attempt to duplicate the conditions present in a typical engine or transmission. No fundamental explanation of foaming exists. The reason that some fluids foam and others do not, and the effect of various parameters such as temperature and pressure, are not clearly understood. How the various anti-foam agents work is also nebulous.

*Background:* The foaming tendencies of lubricants are currently measured using ASTM test method D-892-63, "Foaming Characteristics of Lubricating Oils." AFAPL is working on the development of a test method for the measurement of foaming characteristics under more dynamic conditions than the ASTM test. This work is being coordinated with the Coordinating Research Council Bench Test Panel of the Gas Turbine Lubricant Group.

*References:*

(1) Baum, G., "Foaming Characteristics of Aircraft Oils," WADC-TR-55-475, May 1956.
(2) Schimmoller, H. J., "Foam and Aeration Unit: Modifications and Test Results," AFAPL-TR-68-134, November 1968.

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